Cell Transport Mechanisms and Permeability

exercise 1

Objectives

1. To understand the selective permeability function of the plasma membrane
2. To be able to describe the various mechanisms by which molecules may passively cross the plasma membrane
3. To be able to describe the various mechanisms by which molecules are actively transported across the plasma membrane
4. To understand the differences between how membrane transporters work with and without the expenditure of cellular metabolic energy
5. To define **passive transport, active transport, simple diffusion, facilitated diffusion, osmosis, solute pump, hypotonic, isotonic,** and **hypertonic**

Each cell in your body is surrounded by a plasma membrane that separates the cell from interstitial fluid. The major function of the plasma membrane is to selectively permit the exchange of molecules between the cell and the interstitial fluid, so that the cell is able to take in substances it needs while expelling the ones it does not. These substances include gases, such as oxygen and carbon dioxide; ions; and larger molecules such as glucose, amino acids, fatty acids, and vitamins.

Molecules move across the plasma membrane either *passively* or *actively.* In **active transport,** molecules move across the plasma membrane with the expenditure of cellular energy (ATP). In **passive transport,** molecules pass through the plasma membrane without the expenditure of any cellular energy. Examples of passive transport are **simple diffusion, osmosis,** and **facilitated diffusion. Simple diffusion** is the spontaneous movement of molecules across a biological membrane's lipid bilayer from an area of higher concentration to an area of lower concentration. **Osmosis** is the diffusion of water across a semipermeable membrane. **Facilitated diffusion** is the movement of molecules across a selectively permeable membrane with the aid of specialized transport proteins embedded within the membrane.

In this lab, we will be simulating each of these cell transport mechanisms. We will begin by examining simple diffusion.

Simple Diffusion

All molecules, whether solid, liquid, or gas, are in continuous motion or vibration. If there is an increase in temperature, the molecules will move faster. The moving molecules bump into each other, causing each other to alter direction. Thus, the movement of molecules is said to be "random." If one were to release a drop of liquid food coloring into a large beaker of water, the food coloring molecules would randomly move until their concentration was equal throughout the beaker. The molecules would reach equilibrium through this process of *diffusion.* We define diffusion as the movement of molecules from one location to another as a result of their random thermal motion. **Simple diffusion** is diffusion across a biological membrane's lipid bilayer.

The speed at which a molecule moves across a membrane depends in part on the mass, or molecular weight, of the molecule. The higher the mass, the slower the molecule will diffuse. Normally, the rate at which a substance diffuses across the membrane can be determined by measuring the rate at which the concentration of the substance on one side of the membrane approaches the concentration of the substance on the other side of the membrane. The magnitude of the net movement across the membrane, or flux (F), is proportional to the concentration difference between the two sides of the membrane ($C_o - C_i$), the surface area of the membrane (A), and the membrane permeability constant (k_p):

$$F = k_p A(C_o - C_i)$$

Nonpolar substances will diffuse across a membrane fairly rapidly. The reason is that nonpolar substances will dissolve in the nonpolar regions of the membrane—regions that are occupied by the fatty acid chains of the membrane phospholipids. Gases such as oxygen and carbon dioxide, steroids, and fatty acids are prime nonpolar molecules that will diffuse through a membrane rapidly.

In contrast, polar substances have a much lower solubility in the membrane phospholipids. Certain compounds that are intermediates of metabolism are not usually allowed through the membrane, as they are often ionized and contain groups such as phosphate. Thus, once produced in a cell, they cannot leave even if their concentrations are higher inside the cell than they are outside the cell. From this we can see that it is the lipid bilayer portion of the plasma membrane that is responsible for the membrane's selectivity in what it allows through.

Ions, such as Na^+ and Cl^-, tend to diffuse across a membrane rather rapidly. This suggests that a protein component of the membrane is involved—and in fact, proteins do form channels that allow these ions to pass from one side of the membrane to the other. Remember that the channels are selective. Channels that allow sodium through will not usually allow other ions, such as calcium, through.

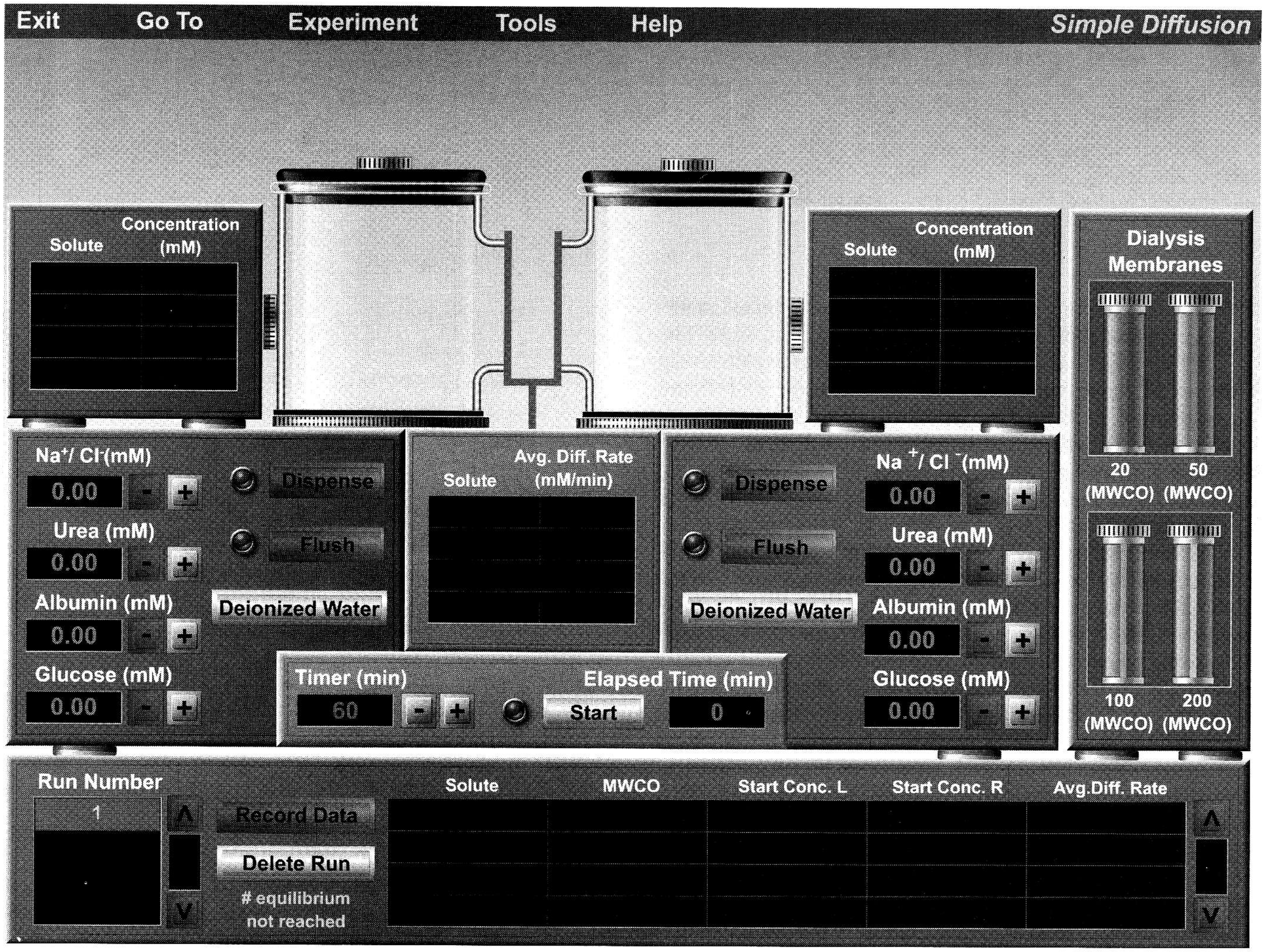

Figure 1.1 Opening screen of the Simple Diffusion experiment.

Diffusion will lead to a state in which the concentration of the diffusing solutes is constant in space and time. Diffusion across a membrane tends to equilibrate so that there are equal solute concentrations on both sides of the membrane. The rate of diffusion is proportional to both the area of the membrane and the difference in concentration of the solute on both sides of the membrane. **Fick's first law of diffusion** states

$$J = -DA\, \Delta_c/\Delta_x$$

where

J = net rate of diffusion (gms or mols/unit time)
D = diffusion coefficient for the diffusing solute
A = area of the membrane
Δ_c = concentration difference across the membrane
Δ_x = thickness of the membrane

Activity 1:
Simulating Simple Diffusion

Follow the instructions in the "Getting Started" section at the front of this manual for starting PhysioEx 3.0. From the Main Menu, select the first lab: **Cell Transport Mechanisms and Permeability.** You will see the opening screen for the "Simple Diffusion" activity, shown in Figure 1.1.

In this activity we will be simulating the process of diffusion across the plasma membrane. Notice the two glass beakers at the top of the screen. You will be filling each beaker with fluid. Imagine that the right beaker represents the inside of a cell, while the left beaker represents the extracellular (interstitial) fluid. Between the two beakers is a membrane holder into which you will place one of four dialysis membranes found on the right side of the screen. Each of these membranes has a different "MWCO," which stands for "molecular weight cut off." Molecules with a molecular weight of less than this value may pass through the membrane, while molecules with higher molecular weight values cannot. To move a membrane to the membrane holder, click on the membrane, drag it to the membrane holder, and let go of your mouse button—the membrane will lock into place between the two beakers.

Below each of the two beakers is a solutions dispenser. You may set how many millimoles (mM) of different solutes (Na^+/Cl^-, urea, albumin, or glucose) you want to dispense into each beaker by clicking on the (+) or (−) buttons beneath each solute name. You may also dispense deionized water into either beaker by clicking the **Deionized Water** button under the beaker you wish to fill. Clicking the **Dispense** buttons under each beaker will then cause the beakers to fill with fluid. Clicking the **Flush** buttons under each beaker will empty the beakers.

At the bottom of the screen is a data recording box. After each experimental run, you may record your data by clicking the **Record Data** button. If you wish to delete the data for any given run, simply highlight the line of data you wish to delete and then click **Delete Run.** You may also print out your data by clicking Tools (at the top of the screen) and then selecting **Print Data.**

1. Using the mouse, click on the dialysis membrane with the MWCO of 20 and drag it into the membrane holder.

2. Adjust the mM concentration of Na^+/Cl^- for the left beaker to 9 mM by clicking the (+) button. Then click the **Dispense** button under the left beaker to fill the beaker.

3. Click the **Deionized Water** button under the right beaker and click **Dispense** under the right beaker to fill the beaker.

4. Set the Timer for 60 minutes by clicking the (+) button next to the Timer display (which will be compressed into 60 seconds.)

5. Click on the **Start** button to start the experimental run. Note that the membrane container descends into the equipment. Also note that the **Start** button is now a **Pause** button, which you may click to pause any run.

6. As the Elapsed Time display reaches 60, note the concentration readings for each beaker in the displays on each side of the two beakers.

7. Once the Elapsed Time display has reached 60, you will see a dialogue box pop up telling you whether or not equilibrium was reached.

8. Click **Record Data** to save the data from this run.

9. Click the **Flush** buttons on both the left and right sides to empty the beakers.

10. Return the dialysis membrane to its starting place by clicking and dragging it back to the membrane chamber.

11. Now, repeat steps 1–10 with each of the remaining dialysis membranes. Be sure to record the data for each run. After each run, flush both vessels and return the dialysis membrane.

Turn to the Periodic Table of Elements on p. 4 of this booklet.

What is the molecular weight of Na^+? ________

What is the molecular weight of Cl^-? ________

Which MWCO dialysis membranes allowed both of these ions through? ________

12. Repeat this experiment using each of the remaining solutes (urea, albumin, and glucose) in the left beaker and deionized water in the right beaker. Be sure to click **Record Data,** flush both beakers, and replace the dialysis membrane after each run. Click **Tools** → **Print Data** to print your data.

13. Fill in the chart below with your results.

Chart 1 Did Diffusion Take Place?

	Membrane (MWCO)			
Solute	20	50	100	200
NaCl				
Urea				
Albumin				
Glucose				

Which materials diffused from the left beaker to the right beaker?

____

Which did not?

____

Why?

____

____

____

____

1 H Hydrogen 1.00794	
Atomic number	
Symbol	
Element	
Atomic weight	

IA 1	IIA 2	IIIB 3	IVB 4	VB 5	VIB 6	VIIB 7	VIIIB 8	 9	 10	IB 11	IIB 12	IIIA 13	IVA 14	VA 15	VIA 16	VIIA 17	VIIIA 18
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.70	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.59	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
55 Cs Cesium 132.9	56 Ba Barium 137.3	57 La* Lanthanum 138.9	72 Hf Hafnium 178.5	73 Ta Tantalum 180.9	74 W Tungsten 183.9	75 Re Rhenium 186.2	76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226.0)	89 Ac** Actinium (227)	104 Rf Ruther-fordium (261)	105 Ha Hahnium (262)	106 Unh Unnil-hexium (263)	107 Uns Unnil-septium (262)	108 Uno Unnil-octium (265)	109 Une Unnil-ennium (266)									

*Lanthanides	58 Ce Cerium 140.1	59 Pr Praseo-dymium 140.9	60 Nd Neo-dymium 144.2	61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
**Actinides	90 Th Thorium 232.0	91 Pa Pro-tactinium (231)	92 U Uranium 238.0	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mende-levium (258)	102 No Nobelium (259)	103 Lr Lawren-cium (260)

Periodic Table of Elements